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Expected role of public transportation services in securing residents' accessibility to the city center in suburban housing development areas

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Abstract

This study aims to examine an expected role of public transportation services in suburban housing development areas of Kobe City in Japan, through calculation of accessibility to the city center using a utility-based measure. The calculation results suggest that, (1) residents' high dependency on car use is evident and leads to a decrease in accessibility for the elderly who may not use a car because of the decline of public transportation services, and (2) although most housing areas have been developed adjacent to railway station, some nearby railway lines do not always contribute to residents' accessibility because of their low level of service and competition with alternative railway or bus services. Under such circumstances, an integrated public transportation network plan is required to be made in these housing areas.

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Keywords: Public Transportation Services; Mode Choice Model; Utility-Based Accessibility Measure; Suburban Housing Development AreCar Dependency

1. Introduction

In many suburban housing development areas of Japan, increase in residents' car use for daily travel has caused a reduction of their public transportation use, which has resulted in a decrease in level of public transportation services. This decrease in service level produces a negative spiral of losing more and more passengers.

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In addition, Japan is facing a rapidly aging population, and accessibility for elderly residents who may not use cars decreases significantly because of poor public transportation services. Under such circumstances, maintaining public transportation services is one of the most important issues for securing accessibility of the elderly in suburban housing development areas.

This study aims to examine an expected role of public transportation services in suburban housing development areas, based on calculation results of a utility-based accessibility measure to the city center. In this study, suburban areas of Kobe City in Japan are selected as a study region. For this purpose, the following two analyses are carried out.

First, dependency on car use for access to the city center by residents is analyzed. Current accessibility to the city center by residents is calculated for all neighborhood districts within development areas in the study region. Accessibility is also calculated when cars alone could not be used among their available travel modes. Then, decrease of accessibility from the current one is shown so that residents' high dependency on car use (in most cases, because of poor public transportation services) is revealed.

Even though most housing areas have been developed adjacent to railway stations so that residents may have easy access to the city center, some residents use alternative public transportation services instead of the nearest railway service. Accessibility to the city center by the nearest railway service and alternative public transportation services are compared so as to demonstrate that some nearby railway lines don't always contribute to accessibility to the city center.

As for accessibility measures, Handy and Niemeier (1997) show that these accessibility measures can be classified into the following three types: One, "cumulative opportunities measures" count the number of opportunities (e.g. retail stores, hospitals) reached within a given travel time or cost. Two, "gravity-based measures", introduced by Hansen (1959), weighs the opportunities by travel impedance such as time or cost. Three, "utility-based measures" founded on random utility theory, can be defined as logsum, derived from choice behavior model such as multinomial logit model or nested logit model (Ben-Akiva and Lerman, 1985). These accessibility measures have been used to evaluate transportation or land-use policies in the past (Geurs and Wee, 2004).

Since cumulative opportunities measure is the simplest method of the three measures, most studies have used this measure to evaluate level of accessibility (e.g. Cheng and Agrawal, 2010; Foda and Osman, 2010; Fielding et al., 1978; Zhao et al., 2003). Gravity-based measures have also been widely used in urban or transportation studies (e.g. Handy, 1993; Hansen, 1959; Luo and Wang, 2003). In order to measure and evaluate current accessibility, it is necessary to take into account various factors, such as individual or household attributes, level of services of travel modes, and geographical features of the area, etc. However, it is difficult for these two measures to reflect the influence of various factors as mentioned above. On the other hand, utility-based measure, which is derived from choice behavior model, can overcome disadvantages (Handy and Niemeier, 1997; Curl et al., 2011; Dong et al., 2006), and take into account the influence of choice set of travel modes on the level of accessibility.

Comparing cumulative opportunities and gravity-based measures with utility-based measure, application of the utility-based measure in practical appraisals of transportation or land-use projects has been quite limited (De Jong et al., 2007). As for applications of the utility-based measure in academic literature, for example, Niemeier (1997) built travel mode and destination choice model using multinomial logit model, and evaluated job accessibility. Geurs et al. (2010) calculated accessibility using National Transport Model (LMS) under TIGRIS XL model framework in the Netherlands. The choice set of the model was composed of five different travel modes. Terayama and Odani (2014) developed destination and mode choice model for shopping travel using nested logit model, and compared results of accessibility to retail stores between urban and suburban residential areas in Kobe City of Japan. Terayama et al. (2015) measured and evaluated accessibility to the nearest railway station in suburban housing development areas in Kobe City, based on an estimation of access mode choice model to the station.

In this study, the utility-based accessibility measure is employed, considering its advantages compared with the other measures as mentioned above. Features of the study are as follows: a mode choice model is built among car, bus and railway, including access modes to a railway station and bus stop using nested logit model. Then, accessibility to the city center which is derived from the mode choice model is calculated by each neighborhood district, and residents' high dependency on car use and the low contribution of the nearest railway service for their access to the city center are demonstrated.

2. Outline of study region and data used

2.1. Study region

Kobe City is the leading city in housing development in suburban areas in Japan. Fig 1 shows the map of the study region, Nishi-ku and Kita-ku of Kobe City, where 51 housing development areas are located in total. The size of these housing development areas ranges from 0.1 to 5.8 km^2 and the populations from 500 to 50,000 people.

In the study region, four railway lines are operated by two railway companies, and the total number of railway stations is 29. The number of train services on each line ranges from 80 to 170 per day. Bus services are operated by five companies and they connect the housing development areas with not only nearby railway stations but also the city center and other destinations. The number of buses serving stops in housing areas ranges from 10 to 120 per day, showing a great difference among housing areas.

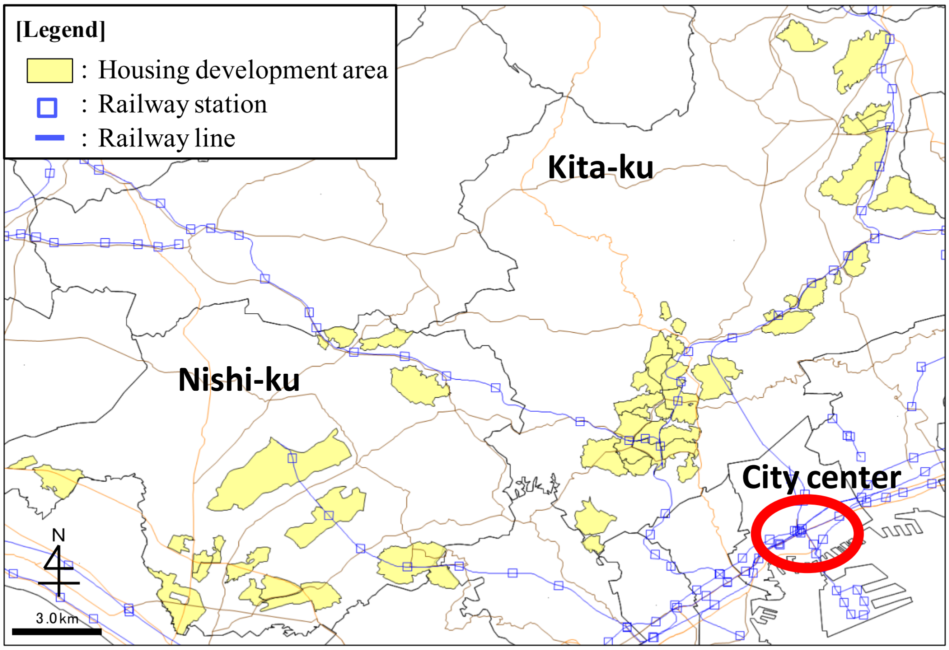


Fig. 1.Map of a study region-housing development areas in the suburbs of Kobe City.

2.2. Data used

In this study, the results of a person trip survey conducted by Keihanshin Metropolitan Area Transport Planning Council in 2010, is used. From this data, home based trips on weekdays, in which travel distance is longer than 5.0 km were selected for the analysis (since travel distance from neighborhood districts to the city center is almost always greater than 5.0 km). The total number of trips is 4,716, and each trip shows the movement between two postal code zones or inside a zone (in most cases, each zone includes a number of neighborhood districts).

Fig 2 shows the composition of trip purposes. Commuting to workplace and school accounts for 69% of all trips, and this is the largest percentage because of using weekday's trip data in this study. The percentages of trips for shopping and medical care are relatively small 5% and 3% respectively, while personal business is 19%. Fig 3 represents the share of travel modes by residents. Railway is the highest, 52%, followed by car 37%, and bus which is only 3%. Distribution of travel destinations of respondents is shown in fig 4. In this figure, destinations are listed in order of number of trips and the ratio of cumulative number of trips is also shown. From this figure, it is clear that the number of trips to the central area of Kobe City is the greatest, which supports the rationale for measuring accessibility to the city center in this study.

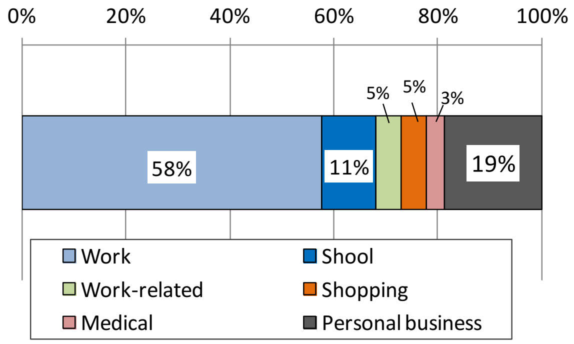


Fig. 2.Composition of trip purposes.

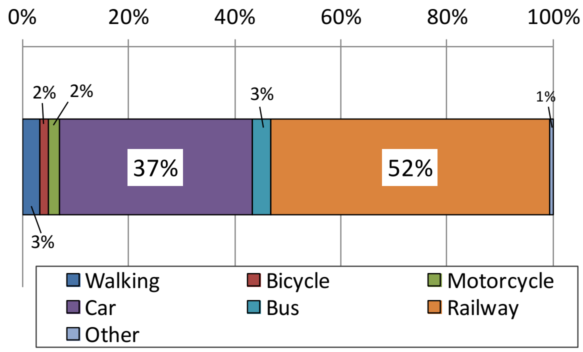


Fig. 3.Share of travel modes.

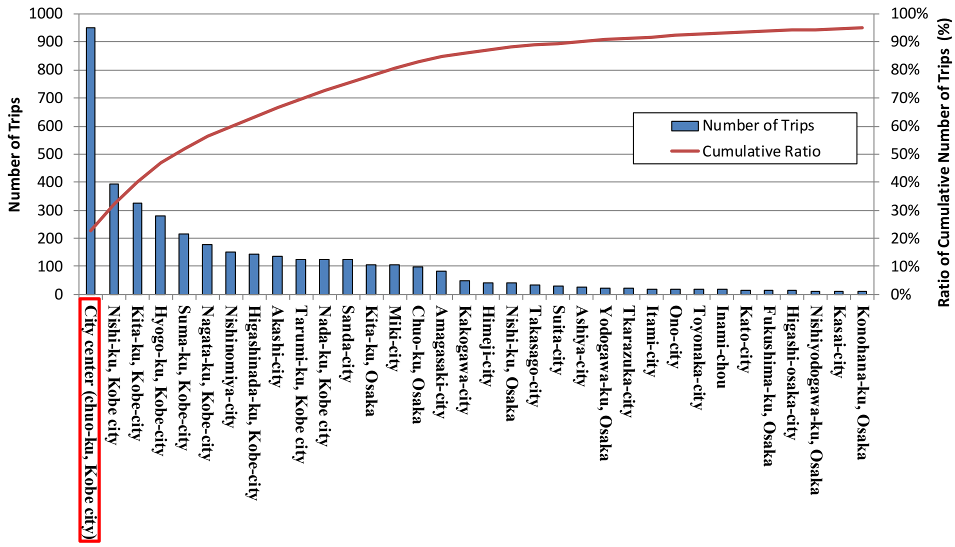


Fig. 4.Distribution of travel destination of respondents.

3. Construction of mode choice model and definition of accessibility measure

3.1. Outline of mode choice model

In this study, a nested logit model is employed for modeling mode choice behavior by residents. Fig 5 represents the model structure used in this study. The upper level shows choice among car, bus and railway, and the lower level shows access mode choice to railway stations or bus stops.

As for the availability of each alternative travel mode for individuals, walking is given for all respondents. Bicycle is given for respondents who own at least one in their households. Car is given for respondents who hold a driver's license or have at least one car in their households. Bus is given for respondents living in a postal code zone where bus stops serving routes to their destinations are located. Railway is given for respondents who can reach their final destinations within 3.0km from exit railway stations (if there are several stations available, it is assumed that respondents choose the nearest exit station to their destinations).

With regard to explanatory variables, all variables are defined as a specific variable for each travel mode. In the upper level, travel time is used for car, and in-vehicle time, number of trains and buses per day and travel cost are used for railway and bus. In the lower level, travel distance to a railway station and bus stop are used for each access mode to a railway station and bus stop. Number of buses per day is used for bus for access to a railway station.

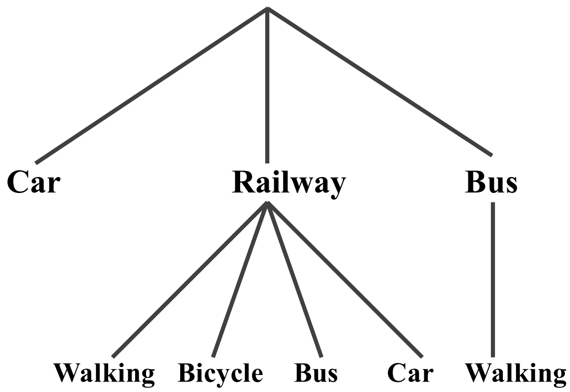


Fig. 5.Model structure.

3.2. Estimation result

Table 1 summarizes the estimation result. Scale parameter is 0.298, satisfying the requirement that it must be between 0 and 1, and is significant at 1%. This means that the model structure assumed here is reasonable. It can be said that the model fits well as adjusted likelihood ratio is 0.328. Signs of all estimated parameters are plausible, and the majority of parameters are significant at 1%, with the exception of in-vehicle time for bus and travel cost for bus.

The estimation result demonstrates the following: as for mode choice in the upper level, the utility of car decreases as travel time increases. The utility of railway and bus decrease as in-vehicle time and travel cost increase, while these utilities increase as number of trains and buses increase.

As for access modes choice in the lower level, the utility of walking, bicycle and car decreases as travel distance to the railway station increases, and travel distance significantly affects the utility of walking since the absolute value of the parameter of walking is higher than that of other modes. The utility of bus for access to railway station increases as travel distance to bus stop decreases and number of buses increase.

Table 1. Estimation result for mode choice model

		estimated parameters	t statics	
Upper level	Travel time (car)	-4.005	-7.18	**
	In-vehicle time (railway)	-0.919	-4.44	**
	Number of trains serving railway station per day (railway)	1.844	5.01	**
	Travel cost (railway)	-0.733	-4.89	**
	In-vehicle time (bus)	-0.956	-1.76	
	Number of buses serving stop per day (bus)	4.623	3.95	**
	Travel cost (bus)	-0.595	-1.53	
	Constant (car)	4.866	4.46	**
Lower level	Travel distance to railway station (walking for access to railway)	-2.468	-14.98	**
	Travel distance to railway station (bicycle for access to railway)	-0.825	-8.73	**
	Travel distance to railway station (car for access to railway)	-0.310	-5.39	**
	Travel distance to bus stop (bus for access to railway)	-2.172	-5.03	**
	Number of buses serving stop per day (bus for access to railway)	1.478	4.39	**
	Constant (bicycle for access to railway)	-3.208	-13.78	**
	Constant (car for access to railway)	-5.229	-19.18	**
	Constant (bus for access to railway)	-5.373	-14.84	**
	Travel distance to bus stop (walking for access to bus)	-4.917	-5.06	**
	Scale parameter	0.298	7.22	**
	N		2591	
	Adjusted likelihood ratio		0.328	

** Significant at 1 % level

3.3. Definition of accessibility measure

Accessibility can be defined as the logarithm of the denominator of a choice behavior model, known as the logsum (Ben-Akiva and Lerman, 1985). Accessibility for an individual n, ACC_n can be written as

$$ACC_n = \ln\left[\sum_{j \in J_n} \exp\left(V_{jn}\right)\right] \tag{1}$$

where V_{jn} is the systematic component of the utility of alternative j and J_n denotes choice set for individual n.

By calculating the logsum derived from the mode choice model in section 3.2, accessibility to the city center can be measured in the study region. It is noted that the estimated parameters of utility function are based on trip data between postal code zones or inside a zone, but the authors calculate accessibility for every neighborhood district included in each postal code zone in the study region.

4. Dependency of car use in current accessibility to the city center

This section demonstrates how current accessibility decreases in a whole study region when residents could not use cars, so that their dependency on car use is revealed in the suburban housing development areas.

4.1. Current accessibility to the city center

The level of accessibility for each neighborhood district is calculated when all available travel modes can be used (the calculation result is referred to as current accessibility). Fig 6 represents spatial distribution of current accessibility on the map of the study region. From this figure, it can be seen that the level of accessibility decreases in inverse proportion to distance from districts to the city center. A high level of accessibility can be seen in some districts, which have not only high level of public transportation services but also easy access to expressway network.

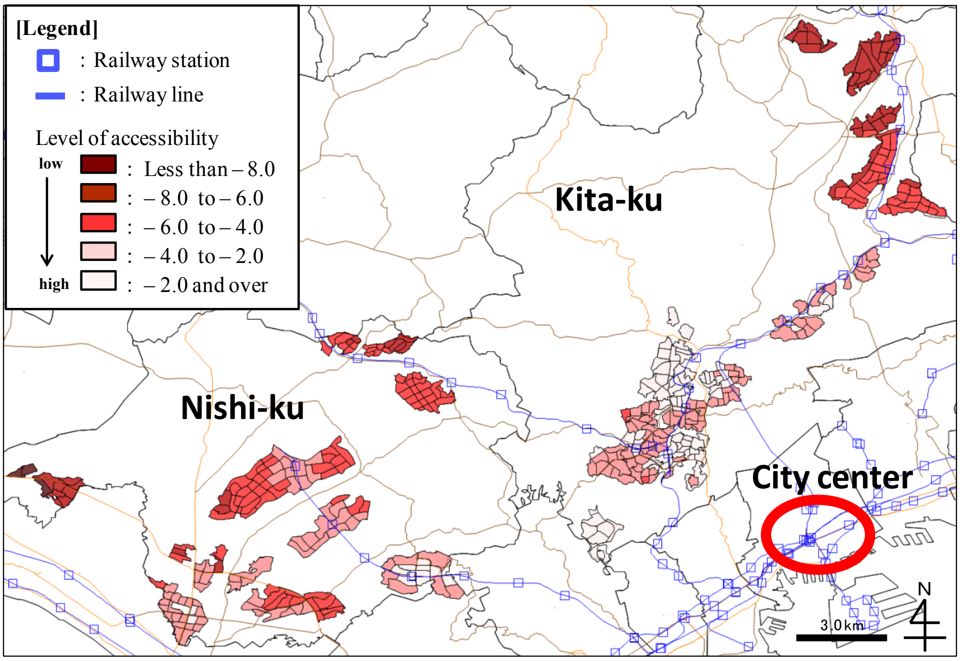


Fig. 6.Spatial distribution of current accessibility when all available travel modes can be used.

4.2. Decreases in the level of accessibility

Accessibility in each district is calculated when cars could not be used (systematic component of the utility of car is equal to 0 in equation (1)), and the calculation result is compared with the current accessibility obtained in section 4.1. The differences between the two calculation cases are assumed to represent the degree to which cars contribute to accessibility to the city center.

Fig 7 shows the spatial distribution of decreases in level of accessibility from the current accessibility for each district when cars could not be used. Decrease is mostly greater, which means dependency on car use for access to the city center is higher, in districts of Kita-ku than in those of Nishi-ku. It can be surmised that among districts which have the same level of current accessibility to the city center, a district with greater decrease in level of accessibility has lower accessibility of public transportation. Therefore, in most districts with high dependency on car use, it is difficult for residents to get high level of accessibility to the city with public transportation services alone.

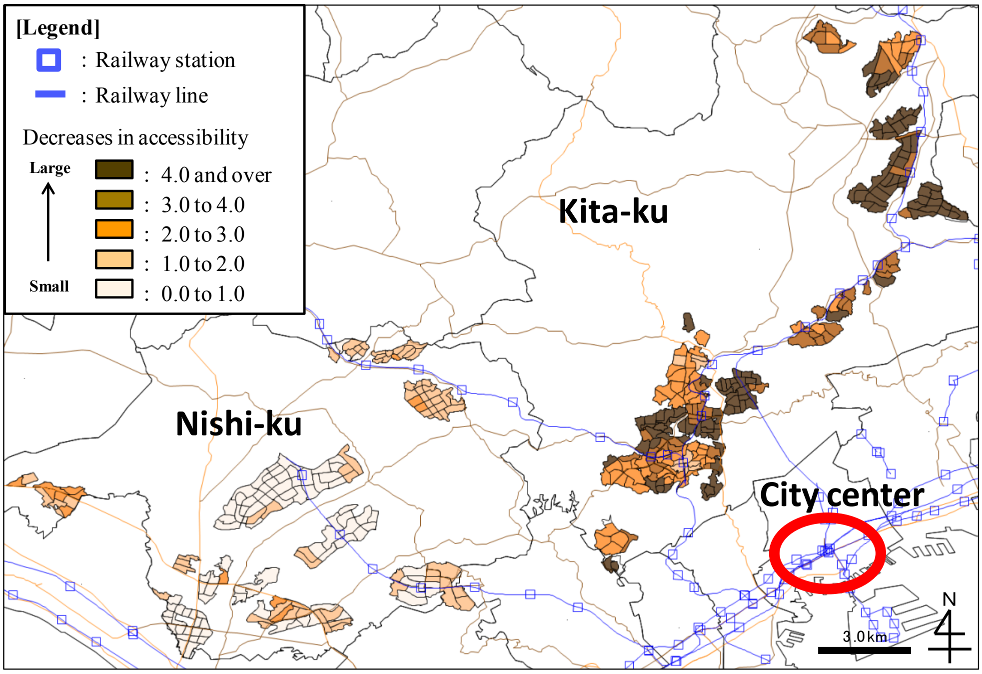


Fig. 7.Spatial distribution of decreases in the level of accessibility when car could not be used.

5. Contribution of public transportation services to accessibility to the city center

In the following section, two development areas adjacent to railway stations are selected for the comparison analysis of accessibility to the city center by the nearest railway service and alternative public transportation services, so as to demonstrate lower contribution of the nearby railway lines to level of accessibility by public transportation.

5.1. Comparison of accessibility between the nearest railway and its alternative railway services

Fig 8 shows a map of one case study area, Nishi-Kobe area in Nishi-ku. Residents can use two railway services, Shintetsu-Ao line and Seishin-Yamate line, to gain access to the city center. Shintestu-Ao line is the nearest railway line to the housing area, and travel distance from this area to its station is about 1.0 km and the number of trains serving the station is 75 per day. On the other hand, Seishin-Yamate line is its alternative railway line, and travel distance to its railway station is about 6.0 km (most railway passengers take bus to the station) and the number of trains serving the station is 176 per day. Travel cost and time are similar among two railway lines: Shintetsu-Ao line is 720 JPY and takes 60 min, while Seishin-Yamate line is 680 JPY and takes 63 min (inclusive of bus fare and travel time to the station).

Accessibility to the city center in each district is calculated for two cases; either the nearest railway service (Shintetsu-Ao line) or the other railway service (Seishin-Yamate line) can be used as a railway option (systematic component of the utility of railway in equation (1) is calculated in two cases of using the nearest railway or the other railway line). Calculation results show which railway line has higher accessibility to the city center, Shintetsu-Ao line or Seishin-Yamate line.

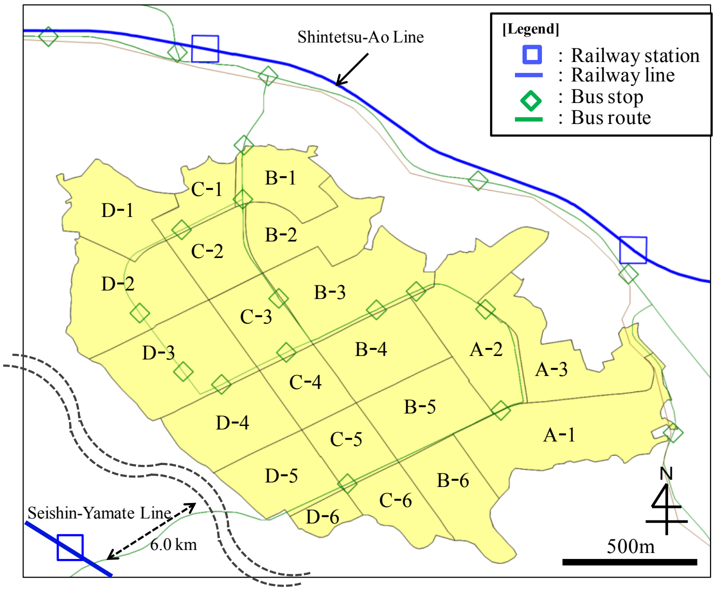
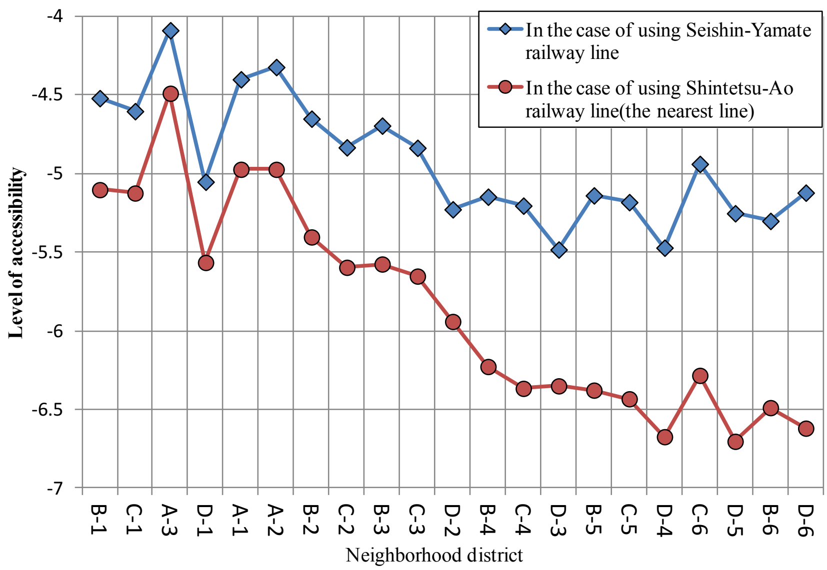


Fig. 8.Map of a case study area, Nishi-Kobe area.



Note: Districts are listed in order of proximity to the nearest railway station on Shintetsu-Ao line from district B-1 to D-6.

Fig. 9.Level of accessibility of districts of two railway lines.

Fig 9 represents level of accessibility by neighborhood districts in two cases of using either Seishin-Yamate line or Shintetsu-Ao line. In this figure, districts are listed in order of their proximity to the nearest railway station (Shintetsu-Ao line).

Although this area has been developed adjacent to the nearest railway station (on Shintetsu-Ao line), accessibility to the city center by the nearest railway line is lower in all neighborhood districts than that by the Seishin-Yamate railway line. The differences in level of accessibility between two railway lines increase as travel distance to the nearest railway station increases. Although two railway lines have similar travel cost and time, significant large differences in level of accessibility between two railway lines can be seen because of a higher number of trains of Seishin-Yamate railway line and bus services to its railway station. Under these circumstances, a majority of residents choose the alternative railway for access to the city center instead of the nearby station.

5.2. Difference between contribution of direct-bus and railway services to accessibility to the city center

Fig 10 shows a map of another case study area, Hinomine-Minotani area in Kita-ku. In this area, residents can access the city center using either direct-bus (bus going directly to the city center) or railway (the nearest railway line to the city center). The number of direct-buses serving a stop per day is 140 while the number of trains serving the nearest railway station per day is 90. Travel time to the city center by two travel modes is similar taking about 35 minutes, but there is great difference in travel cost between two modes: 480 JPY by direct-bus and 710 JPY by railway.

Accessibility to the city center in each district is calculated in two cases; either direct-bus or railway could not be used among available travel modes (systematic component of the utility of either bus or railway equals to 0 in equation (1)). Then, in both cases, decreases in the level of those accessibilities from the current accessibility are obtained. These decreases are assumed to represent the degree to which direct-bus or railway contributes to accessibility to the city center.

Fig 11 represents the decreases in level of accessibility for each district when either direct-bus or railway could not be used. From this figure, it is apparent that the level of accessibility to the city center in most districts, except for only a few districts which are located closer to railway station than bus stop, greatly decreases when direct-bus could not be used than when railway could not be used. This means that the level of direct-bus services (travel cost and number of buses per day) is higher than that of railway. Therefore, it can be deduced that direct-bus contributes more to accessibility to the city center than railway.

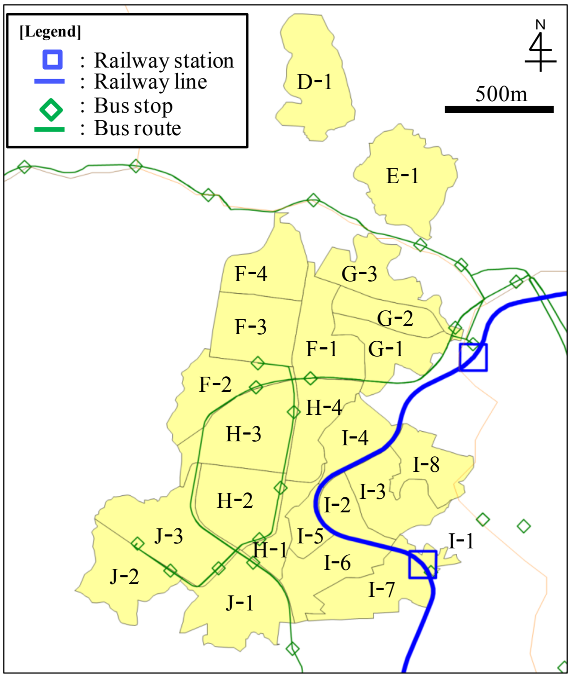
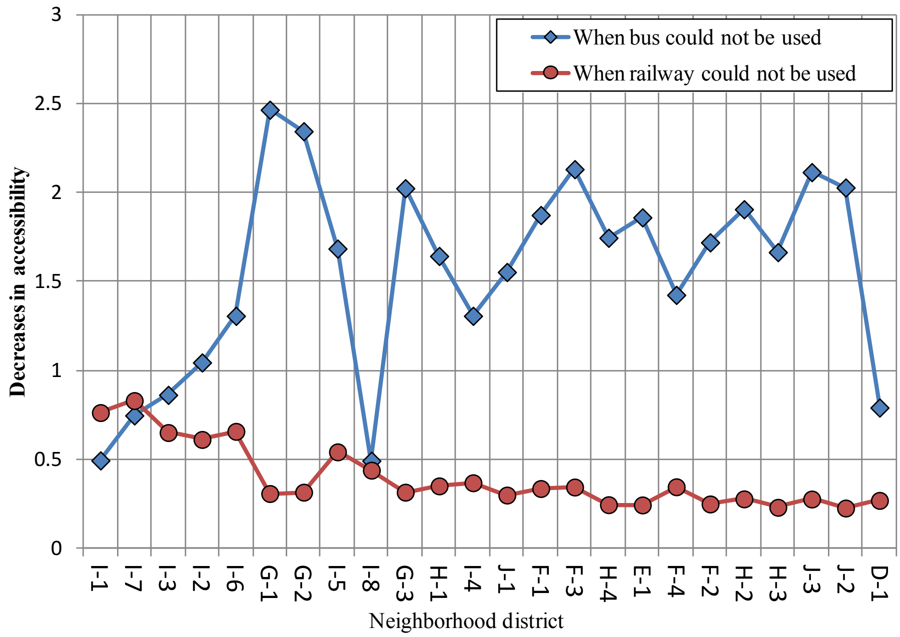


Fig. 10.Map of a case study area, Hinomine-Minotani area.



Note: Districts are listed in order of proximity to the nearest railway station from I-1 to D-1.

Fig. 11.Decreases in the level of accessibility of districts when direct-bus or railway could not be used.

6. Conclusion

The main purpose of this study is to examine an expected role of public transportation services in suburban housing development areas in Kobe City, based on calculation results of a utility-based accessibility measure to the city center. The main findings are as follows.

(1) A mode choice model is built using nested logit model, based on results of person trip survey data on weekdays. Then, accessibility to the city center is measured, which is defined as logsum derived from the mode choice model. As a result, it is possible to evaluate level of accessibility of each neighborhood district quantitatively, from viewpoints of residents' dependency on car use for access to the city center and the contribution of the nearest railway service to their accessibility to the city center.

(2) The current level of accessibility decreases in inverse proportion to distance from districts to the city center. Decreases in level of accessibility when cars could not be used suggests that there is high dependency on car use in suburban housing areas. Comparing districts in Kita-ku and Nishi-ku, Kita-ku has higher car dependency than Nishi-ku, which is caused by lower level of public transportation service in Kita-ku.

(3) Most suburban housing areas have been developed adjacent to the nearest railway station so that residents could have easy access to the city center. However, as shown in two case study areas, because of lower level of the nearest railway service, alternative railway service or direct-bus service contribute much more to the level of accessibility to the city center by public transportation.

(4) The number of elderly residents who may not use cars is increasing because of rapidly aging population, and high dependency on car use in suburban housing development areas is causing a serious problem of decreasing their accessibility. For securing elderly residents' accessibility, it is necessary to explore some way of improving the current public transportation services or introducing new public transport services. On the other hand, in some housing areas, the nearest railway service is not well used contrary to the intention of initial development plan, and is competing with alternative public transportation services. This causes a reduction in nearby railway users and may result in difficulty

continuing its railway operation in the future. Under such circumstances, an integrated public transportation network plan is required to be made in these housing areas.

Finally, the following points should be mentioned as future research: more than half of total trips are for commuting to workplace or school since this study used trip data of weekdays for the analysis. Accessibility should be also calculated based on trip data of weekend which includes more trips for shopping and leisure. City center is only focused as residents' travel destination to measure accessibility, but destinations of secondary and tertiary importance are identified. Accessibility to these travel destinations should be also evaluated in addition to the city center. Elderly residents tend to feel more burdens in traveling by walking or bicycle because most suburban housing development areas are located on hilly land. Factors affecting mode choice behavior by the elderly, such as slope of travel routes, etc. should be taken into accessibility measures.

Acknowledgements

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